Monitoring Arctic Ocean Hydrography
Using Autonomous Underwater Vehicles

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LONG-TERM GOALS

Our goal is to greatly increase access to the Arctic Ocean by creating and demonstrating a safe and economical platform capable of basin-scale surveys. Specifically, we are developing a Autonomous Underwater Vehicle for Arctic research with unprecedented endurance, and the capability to relay data through the ice to satellites. We will provide a means of monitoring changes taking place in the Arctic Ocean and investigate its impact on global warming. The vehicle will also be capable of seafloor surveys throughout the Arctic basin. Such a capability is of national and global interest and importance.

OBJECTIVES

AUV development is focused on an initial experiment, which is to track the Atlantic layer intrusion into Arctic basin. We refer to the experiment as ALTEX for Atlantic Layer Tracking Experiment. ALTEX requires following the 1400 m isobath of the Nansen Basin, with occasional north-south excursions to probe the extent of the warm water intrusion. The vehicle will run at a depth of 275 m, but will obtain a full water column profiles on at least a daily basis. For this mission, the vehicle may not be recovered - data is reported by telemetry buoy. Ice thickness measurements are obtained during the telemetry buoy launch phase.

Figure 1: ALTEX vehicle diving from surface.

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14. ABSTRACT
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To create the desired Arctic survey capability, a number of technical challenges must be mastered. These include developing:

1) An AUV capable of reliably operating fully autonomously for periods of up to two weeks.

2) A power source capable of driving a small vehicle at least 1000 km.

3) Communication systems capable of being deployed from a small AUV, melting through the ice, and transmitting data back via satellite.

4) Navigation systems capable of supporting extended high latitude AUV operations under ice.

While the ALTEX mission requires only a 1500 m depth rating, the depth rating requirement for core vehicle systems has been set at 4500m, to enable access to most of the Arctic Ocean basin.

APPROACH

A modular AUV with parallel mid-body sections has been developed. The general AUV design approach is to minimize the use of pressure housings, putting as many systems as possible in smaller, lighter oil-filled (pressure compensated) enclosures resulting in a small, deep rated system. The ALTEX vehicle is steered by an articulated tail section with a ducted propeller, in contrast with the more traditional control surfaces of previous vehicles. This approach has proven more robust to impacts (which usually occur on launch and recovery) and has improved efficiency as well. Also worth noting is the fact that this system stays inside a 21" diameter.

To achieve the desired range capability, we have been developing a fuel cell energy system constructed by Fuel Cell Technologies, Ltd. The system being developed is pressure compensated and therefore deep-ocean rated. Communication is provided by buoys designed to melt through the ice, and telemeter mission data via Argos. The buoys will are equipped with GPS, so that a position fix can be obtained. Other components of the vehicle are a mix of systems developed for earlier generations of AUVs by the partner organizations.

The fuel cell vehicle section utilizes the high energy density of aluminum, and the oxygen content of 50% peroxide to produce a depth independent refuelable energy source. The complete system for 66 kWh of net energy packaged as a neutrally buoyant section is designed to fit in a 1.9 meter long by 0.51 meter diameter (21 inch) hull section. For this vehicle, the 66 kWh net allows a 1400 km range at 3 Knots for 260 hours. Depth independence is achieved through storage of only solid or liquid reactants and wastes. Energy density for the fuel cell alone based on current tests of full size cells is projected to be over 310 (Wh/kg dry weight).

Communication from the vehicle to shore is provided by a battery of 13 expendable buoys, launched from the vehicle, capable of melting through the ice and transmitting stored data files via Argos. The pre-launch activity of the AUV consists of downloading the data into the next buoy in the launch sequence, and locating a suitable launch site with an ice cover of up to one meter thick. The vehicle then reduces its speed, while maintaining a minimum depth of 50-meters to avoid obstacles such as ice keels. The launcher then releases the designated buoy from the AUV. In its launch configuration, the buoy is slightly buoyant to limit its ascent rate to 1 m/s. The launcher also releases a weight simultaneously with each buoy in order to maintain neutral buoyancy of the AUV.

Upon its release, the buoy ascends towards the surface where it comes to rest against the bottom surface of the ice. After a preset ascent time, the buoy is extended by means of pressurized nitrogen, which increases the separation between its heavy tail and buoyant nose. In this configuration, the buoy becomes stable in an upright orientation against the ice in cross currents of up to 15 cm/s. A pump brings seawater in contact with the Pyrosolve-Z, which reacts exothermically, generating approximately 1500 watts of power for 30 minutes. The steam generated by this process is directed towards the underside of the ice, and as the ice melts, the buoy's rises. When the Pyrosolve-Z is expended, a balloon containing GPS and Argos antennae is inflated. After the antenna deployment, the buoy obtains a GPS fix, and initiates its data telemetry via Argos.

Since the total data which can be transmitted from the buoys via Argos is small compared to the total data acquired by the AUV, a "smart" data transmission software is under development. This routine will transmit data only when a satellite is within field of view of the antenna, thus preserving batteries on the buoy. This process continues until the batteries are expended. However, in the event that a buoy might be recovered, a more complete set of data can be stored in permanent flash memory within the buoy's onboard computer.

The highly interdisciplinary nature of the project is supported by a team of investigators and institutions with complementary expertise. These are:

Dr. James G. Bellingham	MBARI	Project Lead
Mr. William Kirkwood	MBARI	Project Manager
Dr. James E. Overland	Pacific Marine Environmental Lab.	Arctic Science
Dr. John Stannard	Fuel Cell Technologies, Ltd.	Fuel Cells
Dr. Peter J. Stein	Scientific Solutions, Inc.	Through-ice Communications
Dr. Dana Yoerger	WHOI	Navigation, Communication

WORK COMPLETED

Tests in 2001 have verified dynamic control of the AUV in three configurations, from a minimum length vehicle (88 inches) to the full-length system (220 inches) in operations in Monterey Bay. Integration tests have been completed on 1) a heading reference system verified for high latitude operations, 2) a science payload section for the Arctic mission, 3) the buoy launching section, and 4) a variety of supporting systems such as launch and recovery, acoustic tracking, and acoustic navigation systems. The prototype semi-fuel cell system has undergone two rounds of sea-trials.

As this report is being written we are in final preparation for NSF funded Arctic tests of the AUV, navigation, communication buoy, and science sensor systems. The cruise will be carried out in October 2001. The full Arctic demonstration will be carried out in 2002 or 2003, depending on ship availability.

CORE VEHICLE: A modular vehicle has been designed and tested. The design employs four functional sections: a forward payload section, the buoy section, the fuel cell section, and the tail section which contains propulsion, guidance, and control systems. Joining rings allow the vehicle to be opened either by lifting fairing sections out while keeping the vehicle intact, or by separating vehicle sections. The tailcone has successfully been tested and tuned to handle the short vehicle configuration (no fuel cell or buoy section), the intermediate vehicle length (this length includes the fuel cell), and

the full length vehicle. The same tailcone system has also performed well on the BPAUV system in Navy field exercises off of Florida (a Bluefin Robotics project).

SCIENCE INSTRUMENTATION: The science payload consists of two components: sonar for ice draft characterization, and water column sensors for tracking water masses. The goal of the ice sonar is to field a system that is a SCICEX equivalent system. The water column measurements include CTD, nitrate, oxygen, and optical backscatter intensity. These systems have been tested successfully in Monterey Bay, and will be employed on the Arctic cruise.

ICE PENETRATING BUOY: A complete buoy was tested during a March 2001 field test on a lake in Northern Maine. This test was generally successful, but did uncover some problems related to priming of the water pump and extension of the antenna balloon. These problems have been fixed and six buoys have been built for the October 2001 Arctic field test. To deploy the buoys from the vehicle, a buoy launcher was designed, built, and integrated with the vehicle. Two successful tests were carried out during the summer of 2001. Figure 2 shows the launcher and a launch sequence.

NAVIGATION: The primary navigation system for ALTEX is an Inertial Navigation System, which is augmented by any available measurements or estimates of vehicle speed, geophysical measurements (e.g. seafloor bathymetry, and magnetic field direction and strength). The ice-buoys provide periodic navigation fixes by virtue of their GPS, however because there is no communication between the vehicle and the buoys, this information is not available to the vehicle.

Three systems are being evaluated in the Arctic for the ALTEX mission. A SeaDevil system has been obtained from Kerfott on loan and integrated into the ALTEX vehicle for the Arctic tests. Testing of this system in Monterey Bay demonstrated highly promising results. Although data is still being analyzed, performance was substantially better than 0.1% of distance traveled. An Octans north seeking system has also been integrated into the vehicle for Arctic tests. A Litton LN-250 has been acquired, although a late delivery date precluded integration into the vehicle for the Arctic cruise. This system will be ‘bench tested’ for high latitude initialization and navigation performance during the cruise.

FUEL CELL: Fuel cell integration to vehicle was accomplished in spring 2001, culminating in the first sea trials of the fuel cell. During initial integration tests, the fuel cell accomplished over 170 hours of running in the test tank while maintaining the expected parameters. This round of testing was intended to identify issues needing to be resolved prior to Arctic operations. A second round of sea trials of the fuel cell at MBARI during early July 2001 resulted in problems with the fuel cell during vehicle operations. Damage to external structural elements of the fuel cell system resulted in a redesign of some aspects of the fuel cell section. We have proposed additional tests of a modified semi-fuel cell in Monterey Bay during 2002 to ONR.

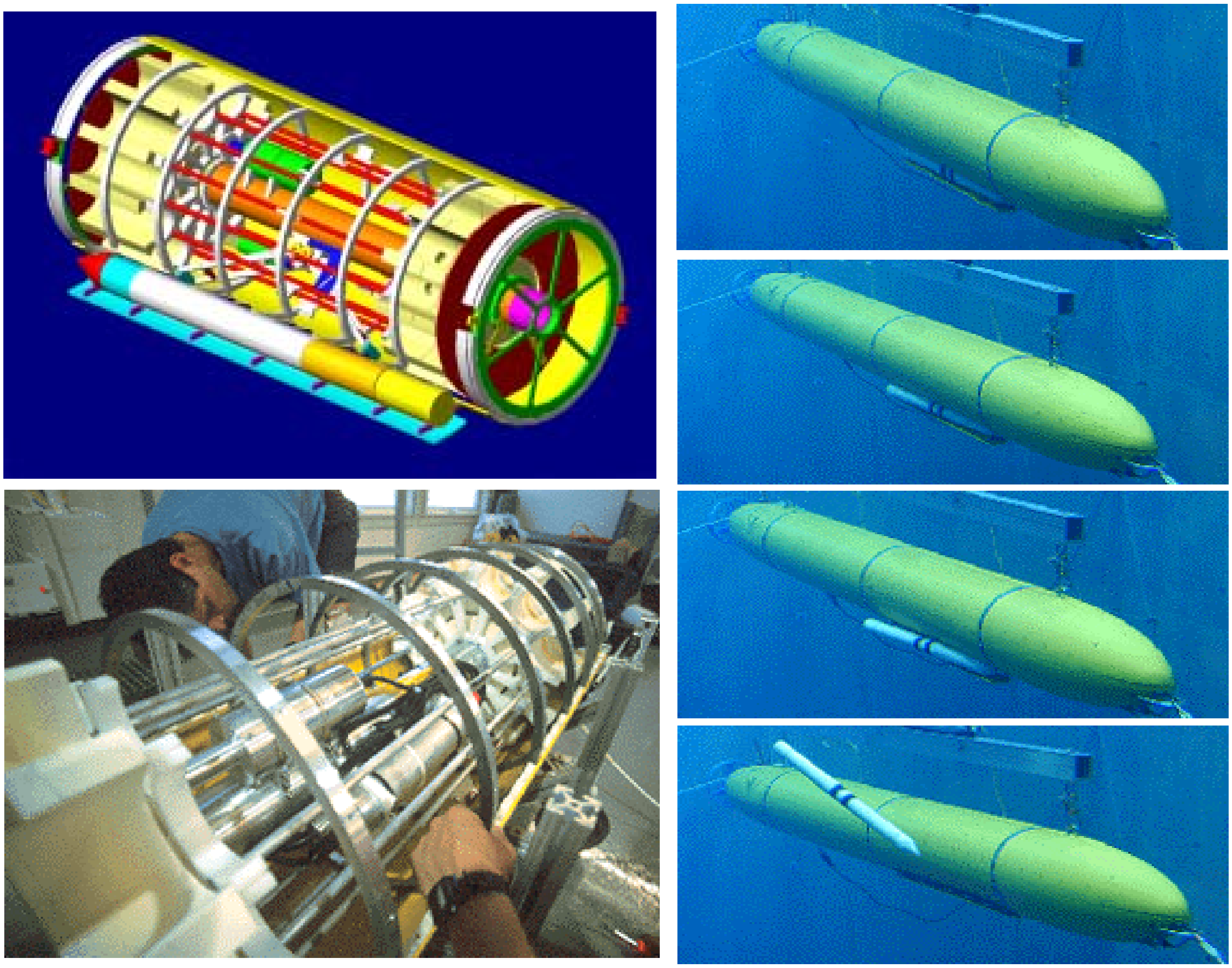

Figure 2: shows pictures of the launcher and a launch sequence from the ALTEX vehicle.

IMPACT/APPLICATIONS

While the developmental effort is presently focused on Arctic Ocean hydrography, this advanced vehicle can be used for a range of oceanographic applications. Other applications in the Arctic Ocean include seafloor mapping. Furthermore, in many ocean regions, the range and navigation capabilities provided by this vehicle would allow shore-based operations. The depth rating of the system allows the vehicle to be used for deep sea vent studies, studies of the sea floor spreading, exploration of the Antarctic ice shelf, and coupled observation/modeling systems in coastal and continental shelf environments. A range of military applications are also enabled, for example early, wide area battlespace characterization from platforms of opportunity.

An important component of this project has been to ensure that the technology is made available to the larger community. To that end, MBARI has successfully transferred the tailcone technology and vehicle software to Bluefin Robotics via a licensing arrangement. Bluefin successfully has employed the tailcone and vehicle software in a variety of vehicles, including Arctic OBS vehicle (Apogee) now

being constructed for NSF, a series of commercial AUVs, and vehicles constructed for mine hunting (the BPAUV).

Additional applications are being pursued. A multi-beam system that conforms to the hull profile is being developed at MBARI, promising a state-of-the art mapping capability for under-ice or bathymetric applications.

RELATED PROJECTS

1) AOSN MURI - Real-Time Oceanography With Autonomous Ocean Sampling Networks: A Center for Excellence – complete.

2) The Battlespace Preparation AUV program, funded under the ONR Innovative Technologies for Organic Mine Countermeasure, is employing a number of the technologies and systems developed under this program.

3) Several STTR and SBIR efforts are coordinated with this program.

4) THALES, Bluefin Robotics, Reson, and MBARI survey vehicle.

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